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Chemical Condensation During Planet Formation

Modeling Parameters

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Model Outline & Objectives

- Model will consist of two phases
  - Matter Agglomeration and Accretion Phase
    - Outputs will include periodic and final composition, mass, and density of forming planet
    - Final outputs of composition of infant planet will be used in condensation phase
  - Chemical condensation phase
    - Outputs will include periodic and final outputs of what and how much of complex molecules or elemental structures have formed, as well as where they have formed.

Elemental Composition of Model

- Starting with system of 1.0001 Solar Masses
- System with universe mass-fraction abundances
- Only considering 13 elements and an “Other” category
  - H, He, C, N, O, Si, Fe, Ba, Ce, Nd, U, Pu, Cm, & Other
    - Pu & Cm are will be considered as results of cosmic radiation interaction with U
    - Other category treated as Cu, midway element between H & Ba.

Elemental Composition, cont.

- Distributed 99.99% of mass of most elements to what is considered to be a young T. Tauri stellar body, the rest left to proto-planetary disk
  - All of the Ba, Ce, Nd, and U were left to proto-planetary disk, as they are trace elements
- This method yielded a star of approx. 0.9995 Solar Masses, and a proto-planetary disk of approximately 18.88 Earth Masses
  - Size and type of star will be important for luminosity comparison later

Elemental Composition, cont.

Element	Abundance by Mass Fraction in Universe	Total Mass in Model	Mass in Star	Mass in Proto-planetary Disk
H	75%	1.492×10^{30} kg	1.4919×10^{30}kg	1×10^{26}kg
He	23%	4.575×10^{29} kg	4.5745×10^{29}kg	5×10^{25}kg
C	0.5%	9.946×10^{27} kg	9.9450×10^{27}kg	1×10^{24}kg
N	0.1%	1.989×10^{27} kg	1.9888×10^{27}kg	1×10^{23}kg
O	1%	1.989×10^{28} kg	1.9888×10^{28}kg	1×10^{24}kg
Si	0.07%	1.392×10^{26} kg	1.3919×10^{26}kg	1×10^{22}kg
Fe	0.11%	2.188×10^{27} kg	2.1878×10^{27}kg	2×10^{23}kg
Ba	1×10^{-6}%	1.989×10^{22} kg	0kg	1.989×10^{22} kg
Ce	1×10^{-6}%	1.989×10^{22} kg	0kg	1.989×10^{22} kg
Nd	1×10^{-6}%	1.989×10^{22} kg	0kg	1.989×10^{22} kg
U	2×10^{-8}%	3.978×10^{20} kg	0kg	3.978×10^{20} kg
Pu	N/A	N/A	N/A	N/A
Cm	N/A	N/A	N/A	N/A
Other	0.22%	4.376×10^{27} kg	4.3756×10^{27}kg	4×10^{23}kg

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Agglomeration & Accretion Phase

- Separated into three parts: gas, planetesimals, and proto-core
  - Proto-core embryo (Alibert et al. 2013) of approximately 0.001 Earth Masses to accumulate gas and planetesimals from proto-planetary disk
  - Gas and planetesimals accumulated based on capture and “decay” rates
- Agglomeration phase will occur over approximately 1 million years (Chambers, 2010).

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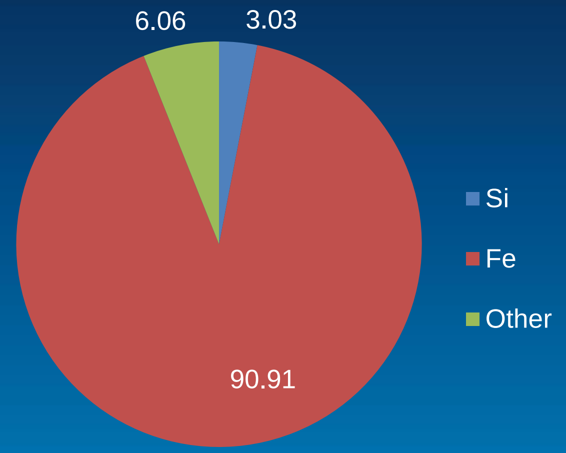
Agglomeration & Accretion Phase, cont.

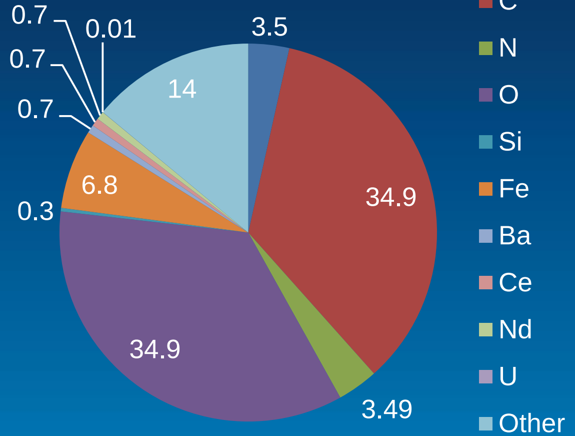
- Planetesimals
  - Of uniform composition, radius, mass, density, etc.
  - R=100m, $2.095739097 \times 10^{14}$ whole and uniform planetesimals for agglomeration
  - Uniform capture and “decay” rate throughout time
- Gas
  - Uniform composition and “decay” rate, but non-uniform accretion rate
  - Accretion rate will increase as temperature in the proto-planetary disk decreases, as the gas will be mostly volatiles

Agglomeration & Accretion Phase, cont.

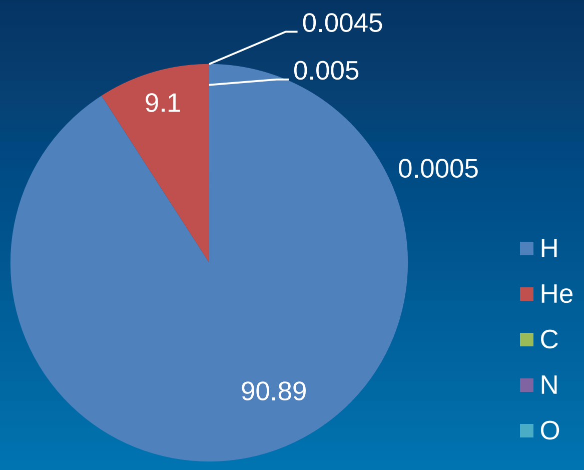
Proto-core Composition



Planetesimal Composition



Gaseous Composition



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Agglomeration & Accretion Phase, cont.

- By taking an initial temperature of 800K in the proto-planetary disk we estimate a radius of formation of 1.225 A.U. from:

$$T = 280 \times \left(\frac{L_{star}}{L_{sun}}\right)^{\frac{1}{4}} \times \left(\frac{R}{1\ A.U.}\right)^{-\frac{1}{2}} \text{ K (Machida et al. 2010)}$$

- We then take the temperature as a function of time to be:

$$\mathrm{T}(\mathrm{t}_1) = 800 - \left(\frac{\mathrm{t}_1}{10^6}\right)(800 - \mathrm{T_f}) \text{ K}$$

where $\mathrm{T_f}$ is the final temperature of the disk

- Final temperature taken to be 300K, subject to change
- Capture and decay rates will be taken such that the matter in the proto-planetary disk runs out at the end of 1 million years

Agglomeration & Accretion Phase, cont.

- Matter will be accumulated in layers
  - Each corresponding to a time (or temperature) step
  - Each layer will also have a radius, beginning with x_{core}, x_1, x_2, etc. where x_{core} is the radius of the proto-core used in formation, and calculated from

$$x_l = \left(\frac{3M_{tot}^2}{4\pi\left(M_c\rho_c + M_p\rho_p + M_g\rho_g\right)}\right)^{1/3} \text{m}$$

where the masses are the total masses of each component at the end of the time step.

- In the final layer the gas and planetesimals will be considered separate, atmosphere and surface

Condensation Phase

- Each layer will only be considered to interact with it's neighboring layers at the layer radius barriers
- All matter present in neighboring layers will be candidates for chemical processes
- Processes will ideally be governed by reaction rates and an estimated inhibiting factor of x/2
  - If x water creating processes occur for some amount of H and O then only x/2 are considered to occur, to account for proximity issues

Condensation Phase, cont.

- Cosmic radiation effects will be considered here, but not during Agglomeration phase
  - Will only be considered to interact with U in processes resulting in Pu and Cm
  - Will only be considered to penetrate top two solid layers
- Temperature and pressure gradients, both linear with radius from infant planet center, will be important in the chemical and condensation reactions occurring

Condensation Phase, cont.

- Temperature will be considered at the layer radii and governed by:

$$T(t_2, x, r) = \frac{7000r - 5500x}{r} - \frac{800t_2}{0.5\times 10^9}\,\mathrm{K}$$

$$p(x, M_{tot}, m) = \frac{Gm(M_{tot}-m)}{4\pi x^4}\,\mathrm{N/m^2}$$

where the temperature decreases in time while the pressure does not

Conclusions

- Though many phenomena in planet formation were not considered, process was super simplified and reduced to a manageable state
- Still need more research on condensation and chemical reactions, as well as defining capture/“decay” rates
- Fine tuning of some parameters may still be required
- More details to come!

References

- Alibert, Y., Carron, F., Fortier, A., Pfyffer, S., Benz, W., Mordasini, C., & Swoboda, D. (2013) Theoretical models of planetary system formation: mass v.s. semi-major axis. *Astronomy & Astrophysics, 558, A109. doi: 10.1051/0004-6361//201321690*
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Thank-you for your time!